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January 25, 2007

Todd Slater
Legacy Site Services LLC
486 Thomas Jones Way
Exton, Pennsylvania 19341

Re: Former Arkema Portland Plant
Scoping Technical Memorandum
Groundwater Source Control Interim Remedial Measure
ECSI No. 398

Dear Mr. Slater:

The Oregon Department of Environmental Quality (DEQ) distributed the *Preliminary Draft Scoping Technical Memorandum Groundwater Source Control Interim Remedial Measures* (IRM) for the Arkema Portland site to the U.S. Environmental Protection Agency (EPA) and members of the Technical Coordination Team (TCT) soliciting their review and comment. Overall the technical memorandum did a nice job of laying out the proposed groundwater source control strategy. The following are DEQ review comments and comments from EPA and the TCT partners which we are carrying forward.

General Comments

1. EPA and partners identified the importance of interim reviews associated with the development of the groundwater model and the desire to participate in the review of the model. DEQ will develop with Arkema a more detailed schedule for the development of the groundwater model that identifies decision points and the opportunities for EPA partner review.

Specific Comments

1. **Section 1.1 Interim Remedial Measure Objectives, First Bullet, Page 2 –** The referenced text states that one of the objectives of the IRM is to "*Prevent migration of groundwater COPCs in excess of their respective Maximum Contaminant Levels (MCLs) (or alternatively risk-based concentrations) ... to the Willamette River*". This objective needs to be expanded beyond MCLs to include contaminant levels in excess of concentrations that would result in unacceptable risk to ecological receptors or humans either from direct or indirect exposure in the river environment per the remedial action objectives of the EPA and Arkema Administrative Order on Consent for Removal Action.

2. **Section 1.1 Interim Remedial Measure Objectives, Page 2** - Add as the last bullet, the following objective: Select and implement an IRM compatible with the early in-water removal action so that the early in-water removal action is not limited in scope by the IRM.

3. **Section 2.2 Previous Remedial Actions, Page 4 –** The last paragraph does not accurately reflect that some of the innovative technologies may not achieve treatment in an appropriate time frame for the early in-water removal action. Revise it to read: However, the longer time required for these in situ technologies may limit their use within the confines of the early in-water removal action (i.e., in-water Engineering Evaluation /Cost Analysis [EE/CA]) schedule. The technology selected needs to be consistent with both the stated groundwater source control objectives and the early removal action schedule.

4. **Section 2.3 Joint Source Control Strategy and Screening, Last Sentence, Page 5 –** Change the last sentence to read: Once finalized, the Source Control Screening evaluation will determine the areas of the site requiring active source control to achieve upland and in-water objectives, or areas of the site requiring further consideration (e.g., site-specific risk evaluations and contaminant fate and transport simulations) for upland groundwater source control.

5. **Section 2.3 Joint Source Control Strategy and Screening, Last Paragraph, Page 5 –** Any areas requiring additional evaluation beyond the weight-of-evidence evaluation conducted in the Source Control Screening need to be identified in the Source Control Screening. DEQ and EPA will need to agree with the proposal (methodology and schedule). Ideally, the areas requiring active source control will be clearly defined prior to Arkema conducting the focused feasibility study (FFS).

6. **Section 3.0 Conceptual IRM Approach and Layout, Page 6 –** DEQ understands that the Arkema team has concluded that a containment barrier wall located at the top of the bank is the most feasible option and achieves the source control objectives. However, the FFS needs to initially evaluate the optimum location for the wall (e.g., top of bank versus toe of bank) to achieve both the early in-water removal action and the upland IRM source control objectives. For example, in the Acid Plant Area a significant contaminant source area (stranded wedge) would remain riverward of a top of bank containment wall. Since it may not be feasible to remove this stranded wedge as part of the early in-water removal action, the FFS needs to evaluate options for a wall in the Acid Plant Area both at the toe of the bank and at the top of the bank.

   The Arkema team has indicated that they question the feasibility of constructing a wall at the toe of the bank in the Acid Plant Area. The FFS will need to balance the feasibility of construction with the impact on the ability to meet the in-water removal action objectives. In general, the wall should be located and constructed to allow the opportunity for the maximum removal of in-water and riverbank principle threat material and minimize the potential for sediment recontamination.

7. **Section 3.0 Conceptual IRM Approach and Layout, Page 6 –** As noted in review comment # 1, additional risk based contaminant levels beyond MCLs need to be considered. The potential for recontamination of sediment via the groundwater migration pathway also needs to be carried forward unless it is documented that alternative concentrations such as MCLs are protective for this remedial action objective.

8. **Section 3.1 Containment Barrier Wall, Page 6 –** Additional discussion and logic is requested in this section regarding the statement that the "barrier wall will not completely encompass the upland source …" It is unclear why Arkema would not want to reduce the influence of up gradient groundwater and subsequently the volume of water behind the wall which must be pumped and treated.

9. **Section 3.1 Containment Barrier Wall, Page 6 –** The design study provides for hydrogeologic studies and modeling to support the wall design. These efforts will need to focus on the hydraulic properties of existing silts and demonstrate they are acceptable as a containment barrier. The FFS should consider alternatives should the silt layer be inadequate to fully control groundwater flux in the IRM area.

10. **Section 3.1 Containment Barrier Wall –** The FFS needs to establish the high water design criteria for the containment barrier wall for the purposes of identifying the top of wall elevation and depth to basalt.

11. **Section 3.1 Containment Barrier Wall –** The FFS needs to consider the associated volume and management of bank soil as part of the evaluation of the various wall/location options.

12. **Section 3.1 Containment Barrier Wall, Page 7 –** As noted in review comments # 4 and # 5, the Source Control Evaluation will identify the groundwater areas to be considered in the FFS for active source control. DEQ and EPA need to agree with the scope and schedule for any proposed site-specific evaluation that would limit the scope of groundwater source control.

13. **Section 3.2 Hydraulic Containment System, Page 7 –** How will the hydraulic containment be evaluated (e.g., compliance wells, modeling, etc.)?

14. **Section 3.3 Other Considerations, Page 8 –** DEQ has indicated that it expects that the pending Hot Spot Evaluation will determine that the fill between the former DDT process waste pond and the river bank in the Acid Plant Area will be a soil hot spot. In order to avoid a conflict between the groundwater IRM and the future upland record of decision the FFS needs to consider the Acid Plant riverbank fill as a hot spot and evaluate the compatibility of the removal or treatment of this fill with the containment barrier wall options. The object of the FFS will be to identify both a preferred groundwater and riverbank fill remedial option.

15. **Section 3.3.2 Cleanup Goals, Page 8 –** See earlier comments on the adequacy of MCLs and process for conducting site-specific evaluations (i.e., review comments # 1, 4 and 5).

16. **Section 4.1.1 Groundwater Modeling, Page 10 –** Add the following sentence to the end of the second paragraph. Each phase will potentially include technical review in coordination with ODEQ, EPA and partners.

17. **Section 4.1.3 Laboratory Treatability and Compatibility Studies, Page 11 –** The first bullet notes that samples will be collected from both major groundwater plumes. As there are more than two and overlapping groundwater contaminant plumes please clarify.

18. **Section 4.1.3 Laboratory Treatability and Compatibility Studies, Page 11 –** This section infers that the FFS is assuming only slurry wall technology, whereas Section 3.1 indicates a comparative analysis of sheet pile and slurry wall. Please clarify.

19. **Section 4.1.4 Focused Feasibility Study, Page 13 –** To facilitate EPA and partner review, DEQ will identify the number of draft FFS copies and recipients for distribution.

20. **Section 4.1.5.1 Draft Design, Page 14 –** Include in the draft design document the site/construction restoration standards and approaches to be used. Also, temporary sediment and erosion controls will be a critical element of the construction and should be discussed in the design criteria memo.

21. **Section 4.1.6 Permitting, Page 17 –** Considering the magnitude of this action, a ARARs analysis is warranted and should be addressed in this section. While the three listed permits may be pursued, the extent of regulatory compliance needs to be evaluated through a ARARs process.

22. **Section 4.1.7 Installation, Startup, and Operation and Maintenance, Page 17 –** This section references dry season construction. The construction schedule needs to accommodate the in-water removal action. This section should reference the in-water removal action and discuss how implementation will tie to the in-water work schedule.

23. **Section 4.1.7 Installation, Startup, and Operation and Maintenance, Page 17 –** Add to the text that both the EPA and DEQ will be involved in construction observation and monitoring.

24. **Section 4.1.8 Source Control Implementation Report, Page 18 –** As noted on Section 3.2, how will the hydraulic containment be evaluated (e.g., compliance wells, modeling, etc.)?

25. **Section 4.1.8 Source Control Implementation Report, Page 18 –** This section states that the source control implementation report will be the sole report pertaining to the source control evaluation. While DEQ agrees with this statement in principle, it is certainly possible that separate evaluation/reports may be required as part of a follow up

weight-of-evidence evaluation, for on-going performance evaluation of the effectiveness of source control measures and other issues that are not apparent at this time.

26. **Section 5.0 Identification of Remedial Technologies for Evaluation, Page 20 –** Because the groundwater IRM is a critical element of the overall site remedy, the FFS needs to evaluate all 5 of DEQ's feasibility study balancing factors identified in Oregon Administrative Rules OAR 340-122-0090 (i.e., effectiveness, long-term reliability, implementability, implementation risk and reasonableness of cost).

27. **Section 5.0 General Comment, Page 20 –** There appears to be an absence of discussion about stormwater (outfalls to abandon), excavation control (how to install the wall), soils management (contaminated excavation spoils), and wall alignment (analysis to select a preferred alignment). These factors should be identified at this point in the planning process.

28. **Section 5.1 Constituents of Potential Concern, Page 20 –** DEQ agrees that the Source Control Screening evaluation will be the initial basis for defining COPCs. See previous review comments # 1, 4, 5 and 12 as they relate to this topic. DEQ anticipates that dioxins/furans will be included in the COPC list. Arkema also will need to confirm that the COPCs identified address the remedial action objectives identified in the EPA/Arkema Order.

29. **Section 5.2 Containment Technologies, Page 21 –** As noted in review comment # 6, the wall may be more optimally placed upland or riverward depending on several factors. It may also provide a structural feature that could limit or enhance the effectiveness of the in-water action. DEQ and EPA will consider how the application of the barrier wall technology detracts or supports the effectiveness of the in-water action.

30. **Section 5.2 Containment Technologies, Page 21 –** Add the following bullet in the second set of bullets: Compatibility with early removal action activities such that these activities are not limited in scope by the IRM.

31. **Section 5.3 Ex Situ Groundwater Treatment Technologies, Page 22 –** The FFS needs to include a discussion of the presence of chloride levels in groundwater and identify groundwater treatment and management options.

32. **Section 5.3 and Section 5.4 Water Handling Options –** The FFS needs to include a discussion of applicable federal and state hazardous waste laws and factor this into the various treatment and waste handling options.

33. **Section 5.4 Water Handling Options, Page 23 –** DEQ approval of discharge of highly concentrated waste streams, even if low in volume, to the public owned treatment works conveyance system (i.e., sanitary sewer lines) is unlikely given the likelihood of leakage from the system.

34. **Figures** - Summary figure(s) from the Source Control Evaluation which identify the groundwater area that requires active source control need to be included in the FFS.

35. **Table 4 –** The table should have another line that covers sheet pile chemical compatibility issues.

36. **Table 5-1 –** The section on Sealed-Joint Steel Sheet Pile Wall should include all the key items from the previous line, Conventional Sheet Pile Wall, since many of those items are part of the Sealed-Joint Sheet Pile.

Appendix A - Appendix A Groundwater Modeling Scoping Technical Memorandum

DEQ and EPA comments on Appendix A are presented separately.

DEQ Review Comments

General Comment

1. The model should be developed in stages, documenting the bases for selecting specific modeling approaches, assumptions, parameter values, etc along the way. The existing document doesn't have sufficient detail for DEQ to approve anything other than Arkema's choice to use a numerical model. Arkema will need to break the model down and do a thorough job of justifying the framework, assumptions and parameter values it uses and the scenarios it simulates.

   a. Possible Stages: I) Model framework - hydrogelogic setting and conceptual model, selection of model domain, boundary conditions, parameter values II) calibration and verification work methods and outcomes, III) predictive simulations for source control alternatives

   b. The document should include specific citations and references for parameter values (i.e. hydraulic conductivities for each layer, which geologic borings were used to construct grid layers), and rationale for modeling assumptions (i.e. basis for assuming contact between overlying alluvial sediments and Columbia River Basalt (CRB) is a no-flow boundary).

   c. A schedule for interim reports and corresponding comment periods should be developed to ensure there is consensus at each stage.

Specific Comments

1. Although, calibration of the groundwater model during late summer makes sense to exclude a complicating factor such as precipitation recharge, Arkema will need to also model worse-case conditions regarding hydraulic control, (high precipitation - *see comment 3* , high gradient periods). There should be an analysis of groundwater elevation - river stage to determine when highest extraction rates would be required.

2. No flow boundary at CRB interface needs greater justification.

3. There should be additional support for recharge assumptions regarding both the total annual recharge and how it's distributed over the year. A careful accounting of site surfaces to estimate percent paved/percent area for direct infiltration, surface runoff is probably warranted.

4. Discuss whether utility interception and infiltration (I&I) has a significant effect on water mass balance.

5. Figures showing model domain and boundaries are needed.

6. A discussion of what evidence or criteria will be used to demonstrate sufficient capture and hydraulic control. Monitoring wells which are going to be used for this demonstration need to be identified.

7. The RI defined 5 hydrogeologic layers while the scoping document identifies breaks out a sixth (weathered basalt). Is there sufficient information to characterize this layer?

8. There needs to be a discussion of vertical gradients in site hydrogeological conceptual model.

9. It appears the Doane Lakes are modeled as having no surface water inputs - is this justified? Discuss hydrology of lakes further.

10. How are geologic conditions interpolated by the model between boring locations?

11. **Appendix A Section A2 –** Include the following text at the end of the paragraph.

    Technical reviewers will have the opportunity to review the development of model design, input parameters, procedures used to construct and calibrate the model, methods used to apply the model to the site-specific environmental problems and results of the model simulations prior to issuance of the summary modeling report and/or inclusion of output from model runs in other related documents. These interim reviews will be coordinated with DEQ, EPA and partners to help meet the stated objectives of the groundwater model.

12. **Appendix A Section A4.1 –** The referenced text states that groundwater model domain will encompass neighboring sites include “GATX”. DEQ assumes that Arkema meant GASCO.

13. **Appendix A Section A.8 –** Particle tracking model outputs are a useful tool to show the extent of hydraulic containment.

EPA Review Comments

1. The use of a three-dimensional model seems acceptable, but there needs to be some commitment to having, or installing, sufficient monitoring wells to make the model functional with sufficient data points. If the facility assumes that there are sufficient data points, including wells at multiple zones, then those should be provided in table and map form.

2. The model should also be calibrated for both the low precipitation (low infiltration)/low river stage season, and also for a high precipitation (high infiltration)/high river stage period.

3. **Appendix A Section A.1**. The use of the ASTM guidelines for groundwater modeling may be acceptable, but it is suggested that the EPA Region 10 modeling guidelines, which are attached, be covered as well since EPA has not reviewed or approved the ASTM guidelines and they may contain issues that do not meet EPA needs.

4. **Appendix A Section A.3.2.2.** While the report does state that "simulations will be solved using a total variation diminishing (TVD) method for solution…" and "MT3DMS is a third-order TVD method with a universal flux limiter", these statements are not sufficient explanations to those not very familiar with the models, and therefore, these statements need to be translated into more comprehensible statements for the non-modeler. What is important about these methods? How will they improve the modeling results?

5. **Appendix A Section A.3.3.3.** The plan states that the model will be constructed with "Groundwater Vistas™, a computer-aided design program….". It is unclear if the agencies will be provided with copies of this code to use independently, or what options will be available for the agencies to request special runs with different parameters, and different views of outputs. Please explain how these issues will be worked out since they are critical to acceptance of the modeling proposed.

6. **Appendix A Section A.4.2**. The statement "storage coefficients specified for these model layers may alternate between confined and unconfined values during the model simulation period" and needs to be explained in more detail since it is not obvious to the reviewers.

7. **Appendix A Section A.4.3.** Boundary conditions second and third bullets. Overall the proposed conditions seem reasonable. The exceptions are the constant-head SW and NE margins of the model grid, and also the no-flow boundaries of NW and SE margins of the model. Please explain why the constant head and no-flows at those boundaries.

8. **Section A.5.2.** The use of an initial recharge of 1 inch where the precipitation per year is 37 inches is not convincing or clear. Secondly, the model should also be calibrated to a wet season when most of the precipitation, and the resultant hydraulic driving forces will

be in play at the site. The use of calibration to the fall season levels is not acceptable since it ignores the major recharges to the site and the entire model domain. Please consider another calibration during the wet season and with a much higher recharge rate, perhaps 20 to 25 inches recharge, or fully document why another value is used and support it with some references for infiltration rates.

9. **Appendix A SectionA.5.3.** Please provide constant head boundaries at the river for the dry and wet periods, similar to the issues in previous section.

10. **Appendix A SectionA.6.1.** The calibration states that "successive simulations until the steady-state head solution reasonably matches the calibration target water levels." Please carefully explain how those levels are defined and where they are listed. Again, it is strongly suggested that the EPA guidelines attached below be used, including tables which show all the key parameters.

11. **Appendix A SectionA.6.2.** Where are the conditions that will be used for calibration (PT-1, PT-2, and PT-3 values need to be listed in report). What makes those values reasonable to use in this modeling calibration? The statement that these tests are considered representative of the ground water zone needs to be qualified by who reviewed those responses and who accepted them for use in this modeling. How do those values compare to other sites in the area? Were these values approved by ODEQ when the work was done? Are they considered acceptable for this modeling? The selected values should also be used as starting points, with some additional model runs which define sensitivity of the model to these parameters.

Please either revise and resubmit the groundwater source control scoping technical memorandum or provide responses to the review comments. Responses to review comments on Appendix A can note that the review comments will be addressed in the documents associated with the model documentation and setup as appropriate. I will be contacting you to schedule a conference call or a meeting to discuss the approach for the development and review of the groundwater model. DEQ looks forward to working with Arkema on this challenging aspect of the project. If you have any questions, please contact me at (503) 229-5538.

Sincerely,

Matt McClincy
Project Manager
Portland Harbor Section

cc: Larry Patterson, ERM
Erik Ipsen, ERM
David Livermore, Integral
Claudia Powers, Ater Wynne
Sean Sheldrake, EPA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
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Environmental Services Division Guidelines March 1, 1994
Hydrogeologic Modeling

These guidelines are based on Environmental Services Division experience in Region 10 with Superfund, RCRA, NPDES, NEPA, and TSCA projects. The guidelines provide a list of elements to consider when conducting ground water and surface water flow, contaminant mass transport, and geochemical modeling. Implicit in these guidelines is that any predictive exercise that attempts to describe the future movement of ground water, surface water or contaminants is a model, be it a qualitative or graphical depiction, a back-of-the-envelope calculation, a hand calculator exercise, or a computer simulation.

The more complex mathematical models or computer calculations are the principal target for these guidelines, though many elements are easily applicable to any type of model. A generic list of computer codes for use at all sites is not provided, nor considered appropriate. Heterogeneity of earth materials, ground water or surface water systems, contaminant sources and species, and project goals requires that each site be evaluated on a site-specific basis with respect to the type of model used and degree of complexity. References noted below, though not exhaustive, contain extensive examples of mathematical approaches and computer codes that have been used in a variety of situations.

Fundamental to the approach taken in these guidelines is that modeling tasks entail a clear progression of thought leading from the question that is posed, to a conceptual model of the hydrogeologic system based on theoretical understanding and site data, to application of the most appropriate model scenarios and tools, to an uncertainty analysis, and finally to an answer to the question posed with acknowledgement of the data gaps and model limitations. Also fundamental to the approach is that modeling tasks be undertaken with an acknowledgement of the intrinsic iterative nature of modeling which commonly points out the need for additional site data or model scenarios.

Two primary topics are addressed by these guidelines. The first concerns information which should be supplied in a work plan or scoping document pertaining to the modeling protocol. The second topic concerns the preferred use of computer codes that are in the public domain.

A. Modeling Protocol.

A modeling protocol should be developed and provided in a work plan, sample plan, or scoping document. This protocol should provide planning information and identify the goals of modeling. In the modeling protocol, all data for model input parameters and boundary conditions that need to be collected during the field work should be identified and their method of collection described in the sample plan. The following items should be included in the modeling protocol.

1. The goals of the modeling should be stated in a manner that allows easy comparison to modeling results so that a determination can be made as to whether goals were achieved.

2. A site-specific conceptual model of the hydrogeologic system should be presented in graphical form (including scaled maps and cross-sections) with associated discussion and should be based on available data. The conceptual model should include the mathematical relationships that are used to describe the principal hydrogeologic processes of concern. Data gaps, assumptions, and uncertainties should be described in the conceptual model.

3. The technical requirements needed to achieve the goals should be discussed, such as need for numerical versus analytical approach, 2-D or 3-D requirements, possible need for simulation of the unsaturated zone, multiphase flow, or tidal influence, and requirements for simulation of dispersion, retardation, degradation, or chemical reactions.

4. If computer modeling is needed, the appropriate computer codes should be identified. The ability and limitations of the proposed computer codes to meet the conceptual model requirements should be discussed. It is critical to match the proposed code to the site conditions and the availability of data, including good justification for the input parameters.

5. Boundary and initial conditions and other input parameters should be identified, and procedures for model calibration and uncertainty analysis should be described.

    a. Specify the input parameters that will have assumed values, and indicate the basis for the assumptions.

    b. Specify the input parameters that will have values derived from site-specific information. A brief description of data collection methods should be provided (or a reference to a section in a sampling and analysis plan should be provided). Also, the quality of and variability associated with input parameters derived from site specific data should be described.

c. Parameter estimation techniques and associated uncertainties should be identified.

d. A plan for parameter sensitivity analysis should be outlined to compare model sensitivity with variations in input parameters.

6. Model documentation should incorporate the Elements of Technical Analysis listed in the Appendix. Two key elements of a model report should be noted. Uncertainty analysis of the results is necessary. This analysis can be either qualitative or quantitative, depending on the scope of the modeling. Also, a computer modeling report should have an appendix that includes copies of critical model input and output files, and the report should be accompanied by a floppy disk containing all the input files used in the evaluation.

B. Computer Codes.

The ESD hydrogeologic staff advises the use of public domain computer codes over proprietary codes for the following reasons.

1. The Region 10 technical staff and EPA consultants are familiar with a number of public domain computer codes. In addition, the regional staff and consultants can more easily gain familiarity with computer codes not used to date in Region 10 through support from other EPA modeling experts when the code is in the public domain.

2. In an oversight capacity the Region 10 technical staff or EPA consultants do not commonly have time to become familiar with the operation of proprietary computer models. This is an especially significant factor at sites which have relatively short time schedules established for EPA review.

3. The Region 10 staff and EPA consultants do not have free access to proprietary codes and must purchase them or make special arrangements for their use in a proprietary manner. This is unjustifiable in light of the many, high quality public domain codes that are available and have undergone extensive peer review and validation.

4. Modeling projects under most EPA programs are subject to public review. Proprietary computer models are not easily available to the public. Those people in the public sector who are familiar with modeling or who have access to hydrogeologic consultants should have the opportunity to evaluate the basis, validity, and sensitivity of modeling results.

5. By discouraging or limiting technical review, the use of proprietary computer codes generally tends to promote predictive calculations as a black-box science inappropriate for public evaluation of hazards to health and the environment.

C. References.

Other useful references applicable to the discussion of appropriate modeling methods include the following:

Anderson, Mary and Woessner, William, 1992, Applied Groundwater Modeling: Simulation of Flow and Advective Transport: Academic Press Inc., 341 p.

Bond, Frederick and Hwang, Seong, 1988, Selection Criteria for Mathematical Models Used In Exposure Assessments: Ground-water models: U.S. Environmental Protection Agency, EPA/600/8-88/075

Javandel, Iraj, Doughty, Christine, and Tsang, Chin-Fu, 1984, Groundwater Transport: Handbook of Mathematical Models: American Geophysical Union, Water Resources Monograph 10, 228 p.

National Research Council, 1990, Ground Water Models: Scientific and Regulatory Applications: National Academy Press, 303 p.

Office of Solid Waste and Emergency Response, 1992, Ground-Water Modeling Compendium: U.S. Environmental Protection Agency, EPA/500/B-92/006

U.S. Environmental Protection Agency, 1994, Agency Guidance for Conducting External Peer Review of Environmental Regulatory Modeling: Agency Task Force on Environmental Regulatory Modeling (ATFERM), 16 p.

,Van der Heijde, Paul, Bachmat, Yehuda, Bredehoeft, John, Andrews, Barbara, Holtz, David, and Sebastian, Scott, 1985, Groundwater Management: The Use of Numerical Models: American Geophysical Union, Water Resources Monograph 5, 180 p.

Van der Heijde, Paul K.M., El-Kadi, Aly I., and Williams, Stan A., 1988, Groundwater Modeling: An Overview and Status Report: U.S. Environmental Protection Agency, EPA/600/2-89/028, 242 p.

Appendix to Environmental Services Division Modeling Guidelines March 1994

Elements of Technical Analysis

I. Management Objectives

* Scope of problem
* Technical analysis objectives as they relate to management objectives
* Level of analysis required
* Level of confidence required

II. Conceptual Model

* System boundaries
* Important time and length scales
* Important processes
* System characteristics
* Source characteristics
* Available data sources (quality and quantity)
* Data gaps
* Data collection programs (quality and quantity)

III. Choice of Technical Approach

* Rationale for approach in context of management objectives and conceptual model
* Reliability and acceptability of methodology
* Important assumptions

IV. Parameter Estimation

* Data used for parameter estimation
* Rationale for estimates in the absence of data
* Reliability of parameter estimates

V. Uncertainty/Error

* Error/uncertainty in input and boundary conditions
* Error/uncertainty in loadings
* Error/uncertainty in specification of environment
* Structural errors in methodology (e.g., effects of aggregation or simplification)

VI. Results

* Tables of all parameter values used for analysis
* Tables or graphs of all results used in support of management objectives or conclusions
* Accuracy of results
* Conclusions of analysis in relationship to management objectives
* Recommendations for additional analysis, if necessary

DEQ-DC1